

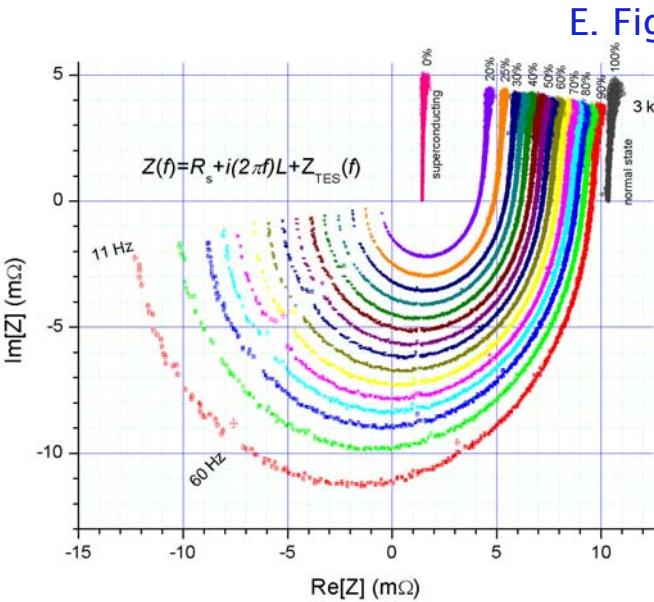


Progress on TES Microcalorimeters

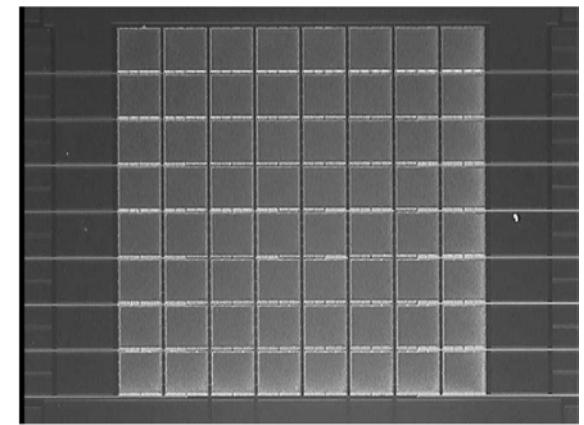
NIST



NIST



E. Figueroa-Feliciano
S. Bandler
K. R. Boyce
J. A. Chervenak
F. M. Finkbeiner
R. L. Kelley
M. J. Li
M. A. Lindeman
F. S. Porter
C. K. Stahle
T. Stiles
S. W. Deiker
J. Beall
J. Beyer
R. Doreise
L. Ferreira
G. C. Hilton
K. D. Irwin
L. Vale
C. Reintsema
J. Ullom
Y. Z. Xu



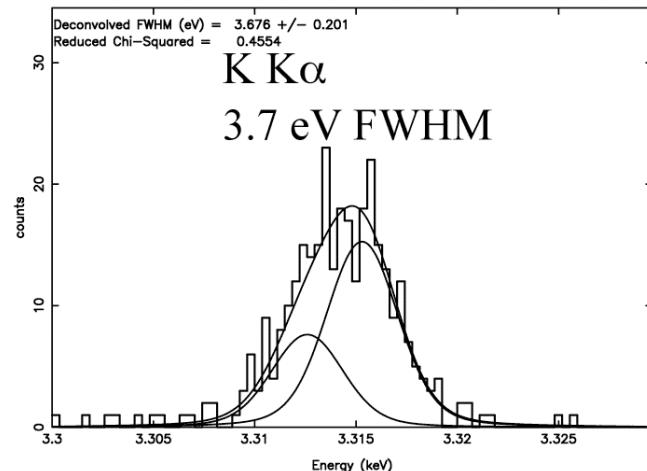
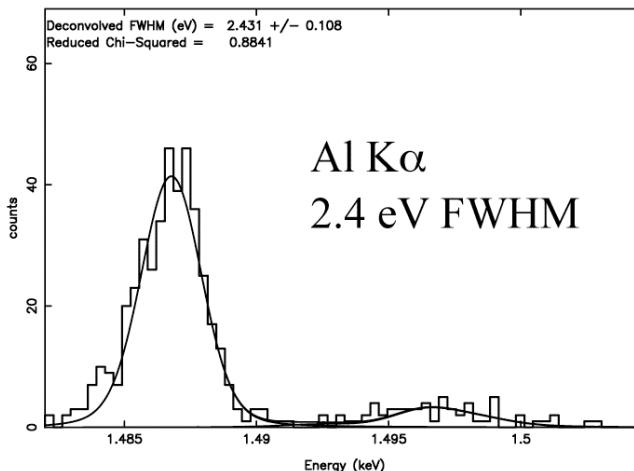


Overview



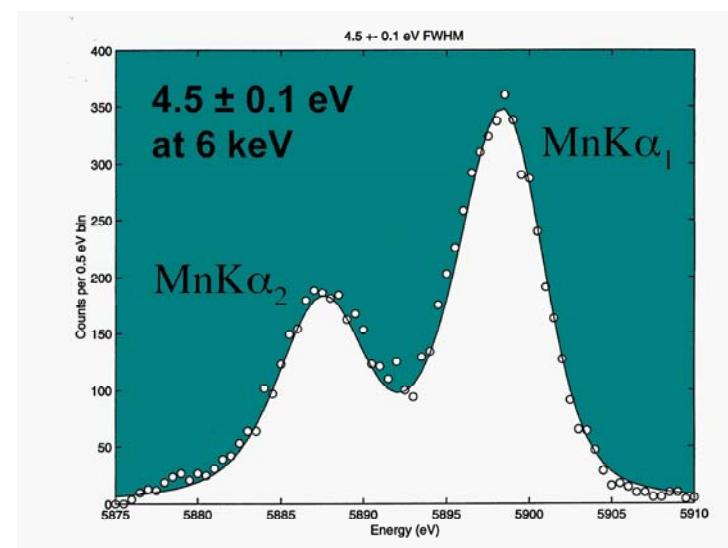
- **Single Pixel TES development**
 - Understanding the TES transition
 - Fabrication and testing of novel geometries
- **Schedule for Arrays**
 - 2 x 2 demo (Dec 2002)
 - 2 x 8 demo (Jun 2004)
- **Arrays**
 - GSFC approach and status
 - NIST approach and status
- **SQUID MUX**
 - Latest design
 - Testing
- **Conclusion**

Single-pixel Progress



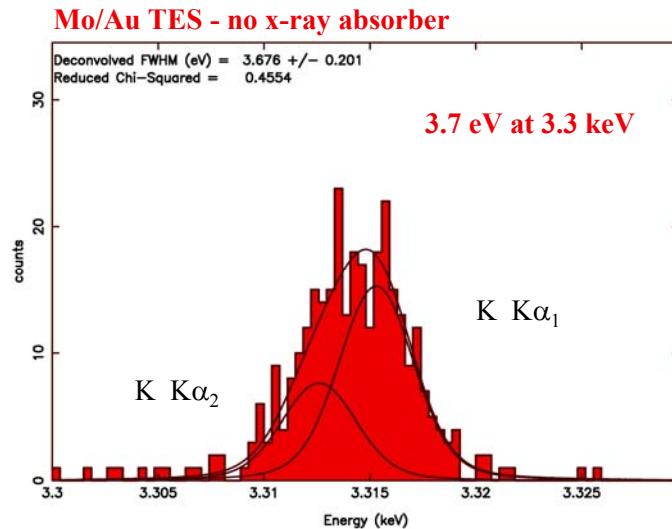
TESs have demonstrated high resolution spectroscopy in the Constellation-X band.

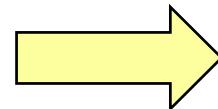
We are currently limited by an excess noise of unknown origin



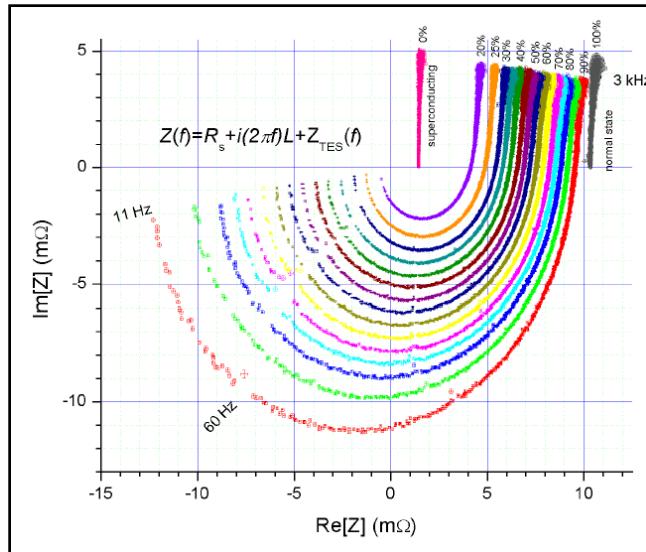
Getting at the Physics of the Noise

- In order to eliminate the excess noise, we need to understand the physical state of the TES
 - What is the heat capacity of a TES in the transition?
 - What is actually happening inside a TES in the phase transition?
 - What changes as the resistance changes?
 - Is it a stochastic process?
 - Can we make it more deterministic, and would that eliminate the noise?



 <2 eV?

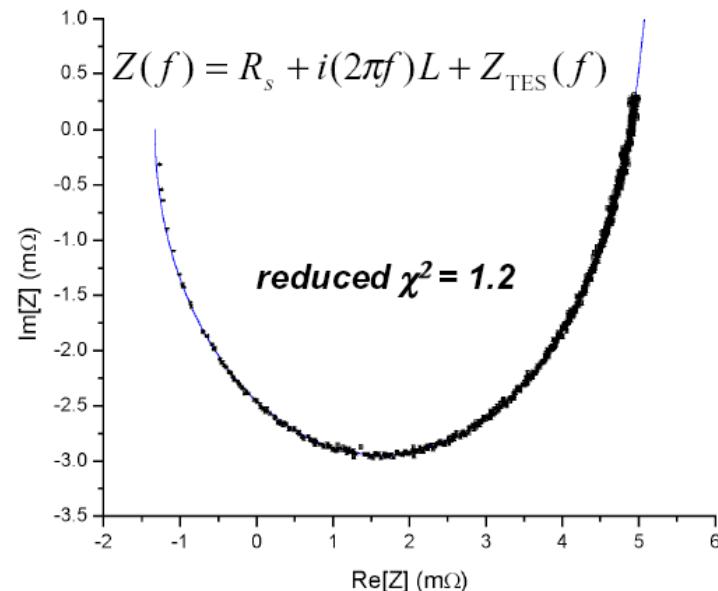
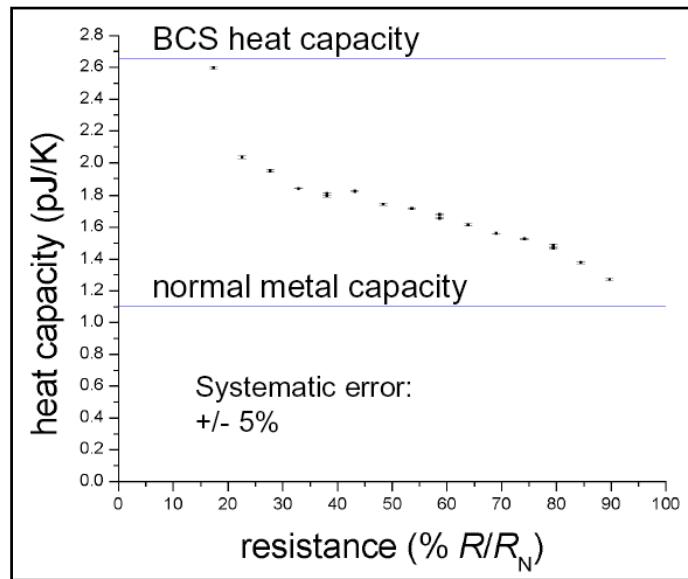
Recent Progress and Issues (cont.)



Impedance measurements yield device parameters:

Measured parameters
 $G=344 \text{ pW/K}$
 $I_0=29.5 \mu\text{A}$
 $R=2.05 \text{ m}\Omega$
 $R_S=1.45 \text{ ohms}$
 $T_0=98.5 \text{ mK}$

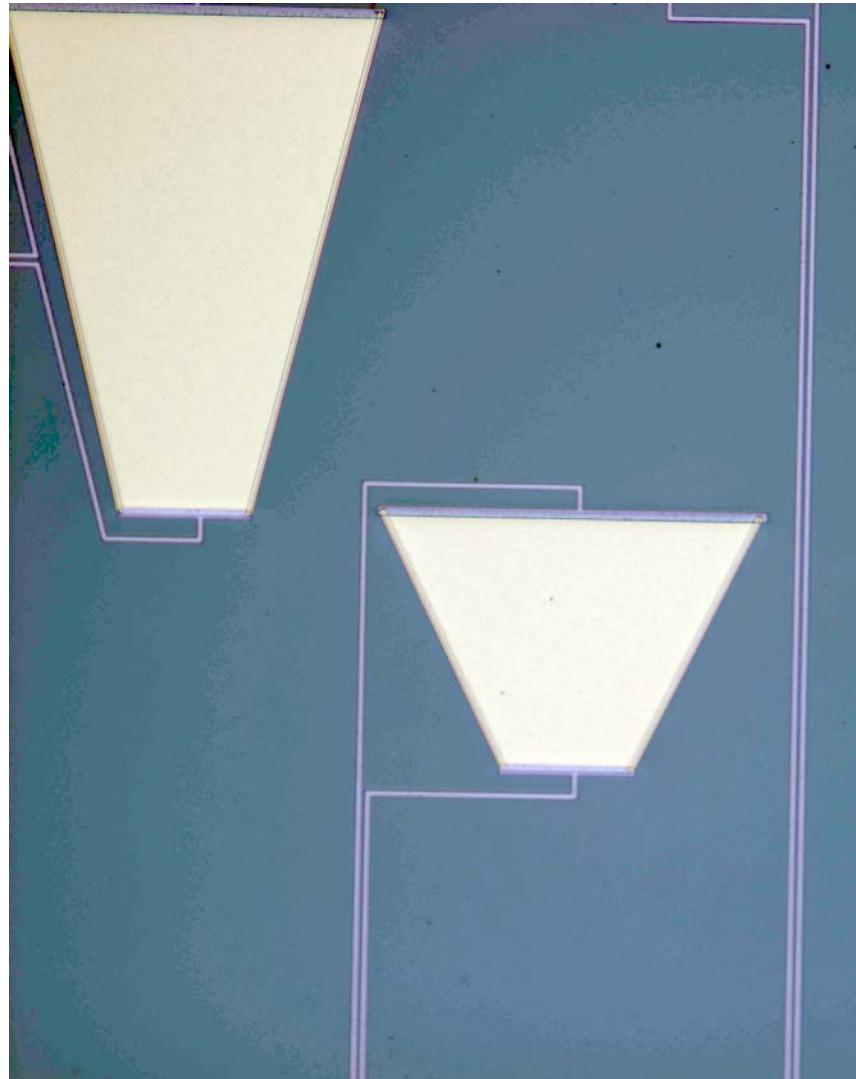
Free parameters and statistical errors
 $\alpha=172.3 +/- 0.7$
 $\beta=0.8518 +/- 0.0008$
 $C=(2.034 +/- 0.008) \text{ pJ/K}$
 $L=(262.9 +/- 0.6) \text{ nH}$



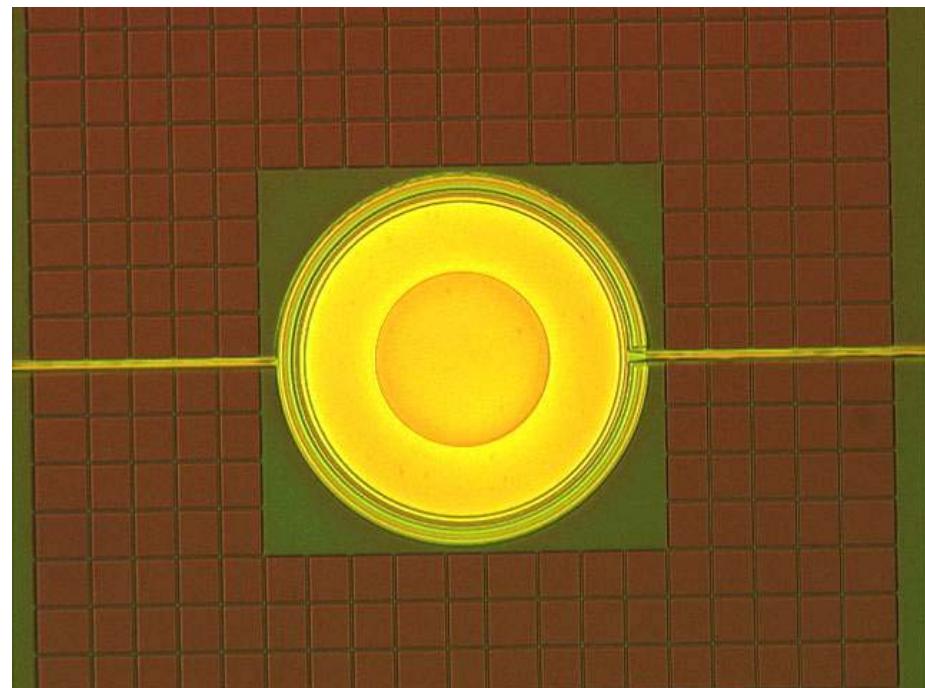


Novel TES geometries

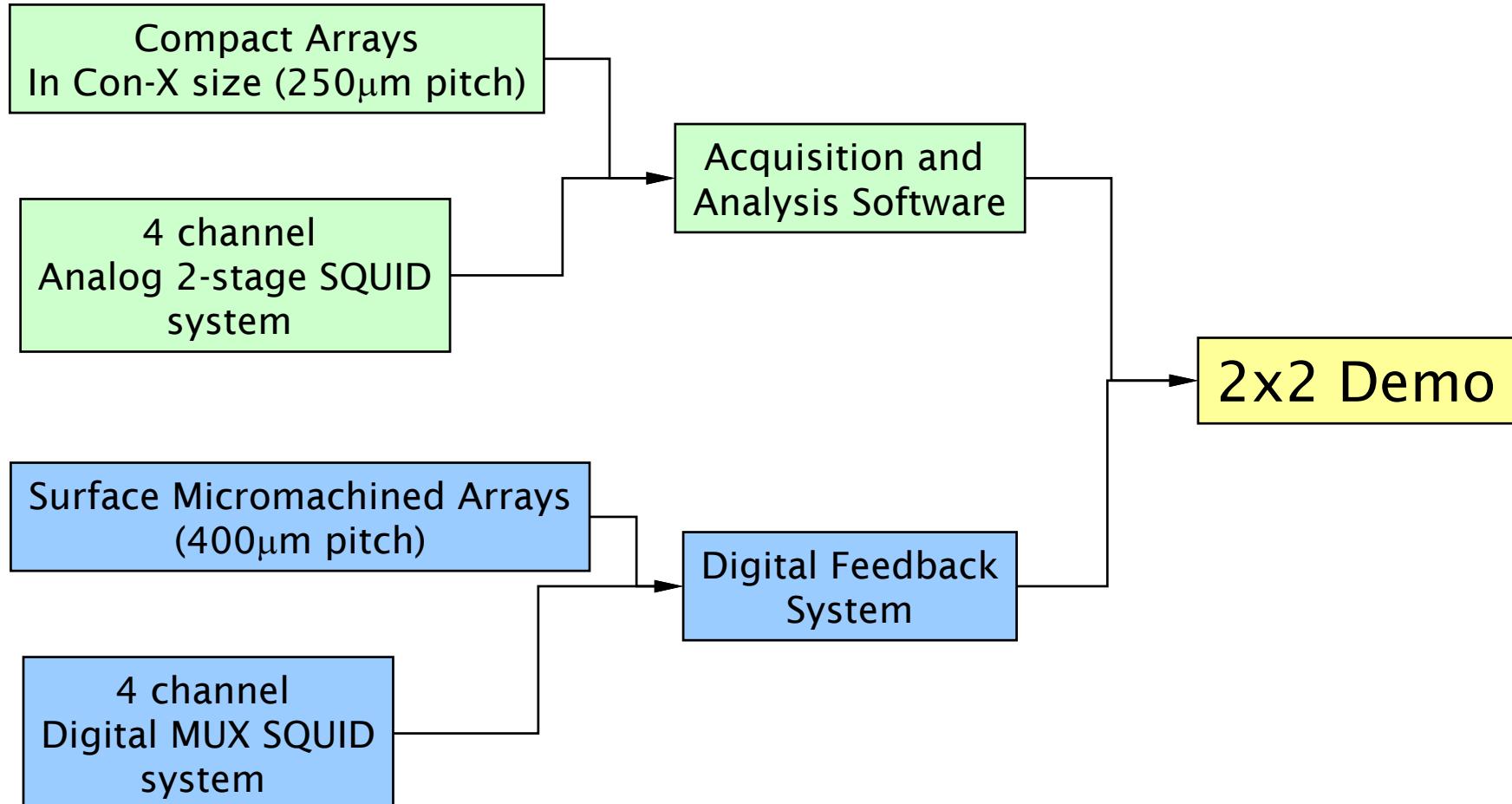
NIST



NIST



Path to the 2x2 Demo

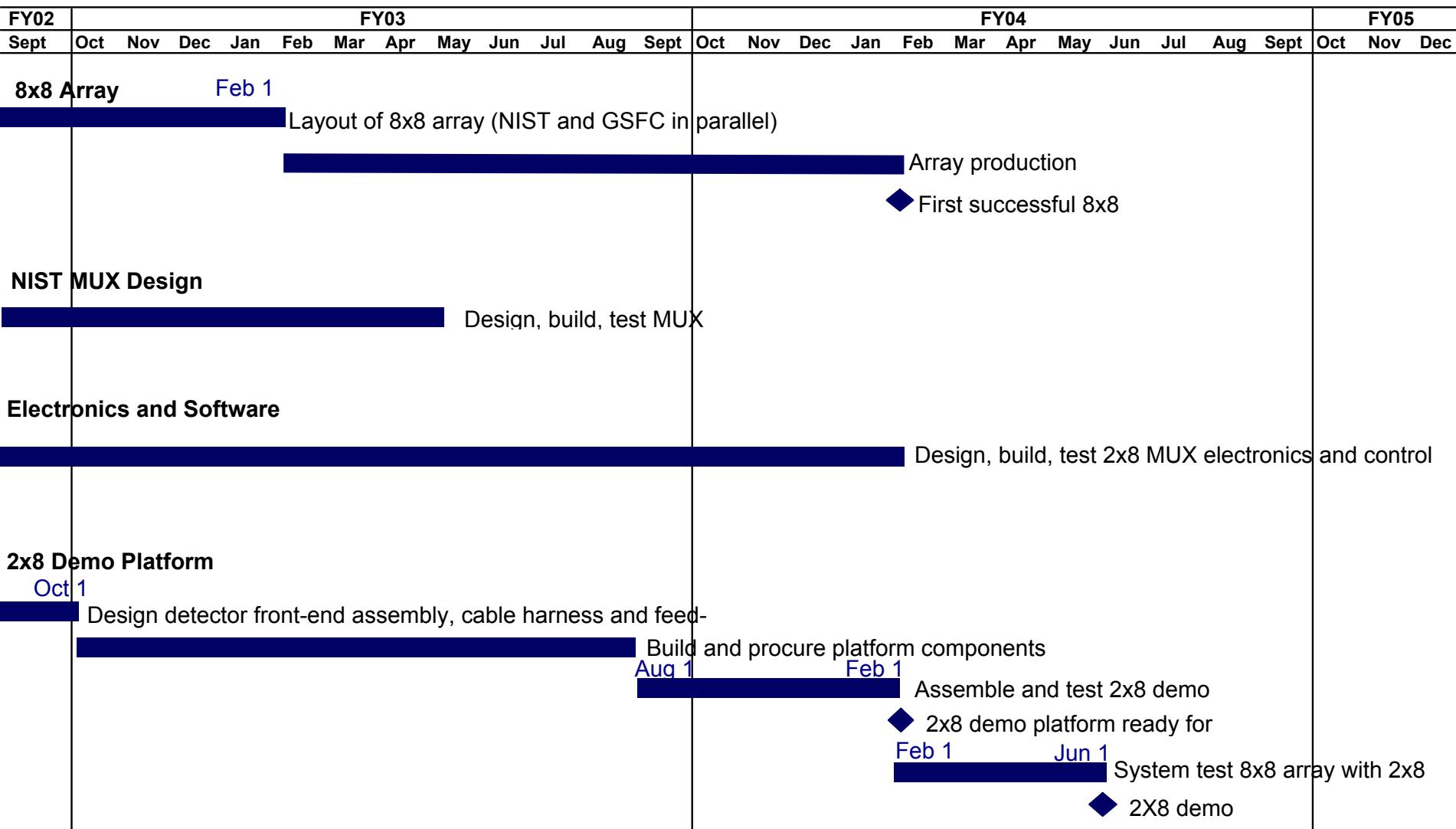




Schedule (2 x 8)

NIST

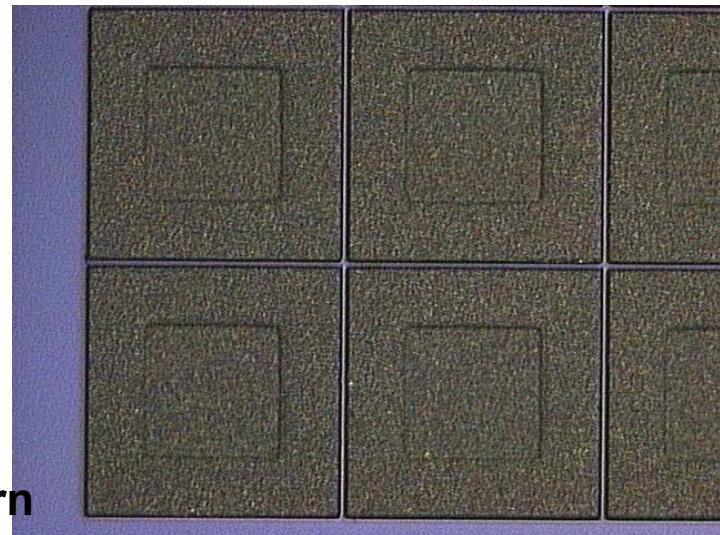
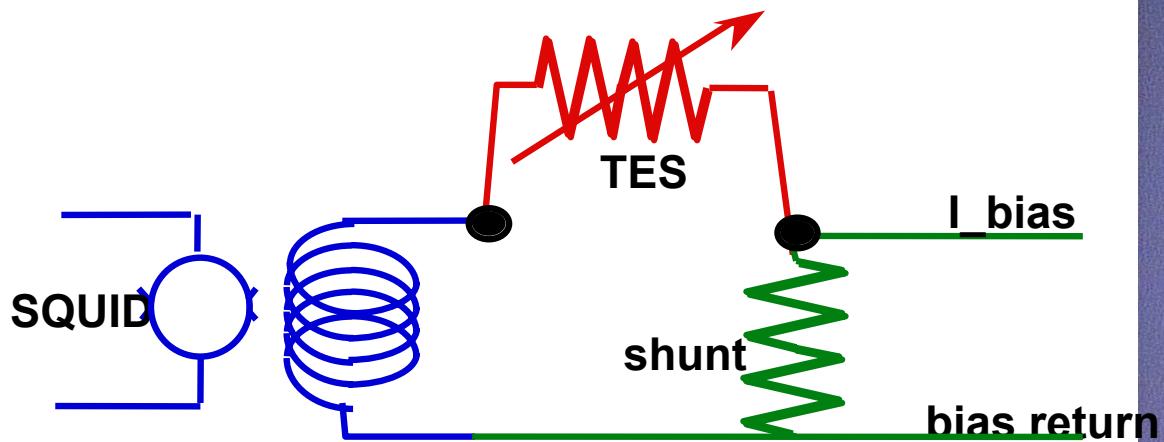
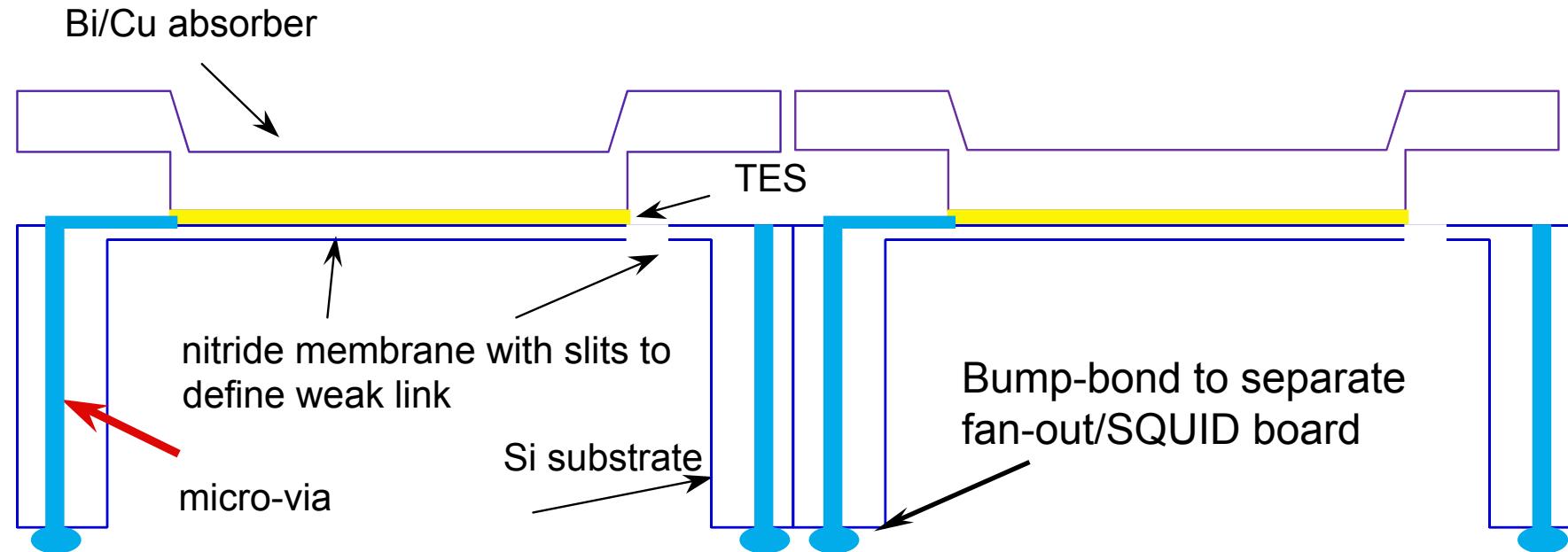
Preliminary TES 2x8 Demo Schedule





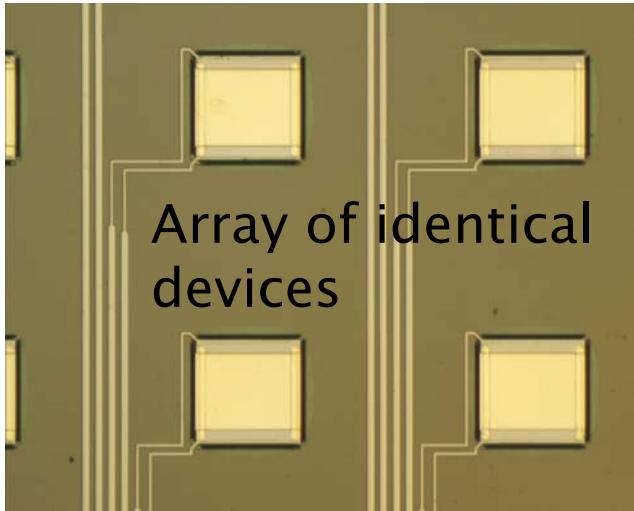
Goddard TES Arrays

NIST

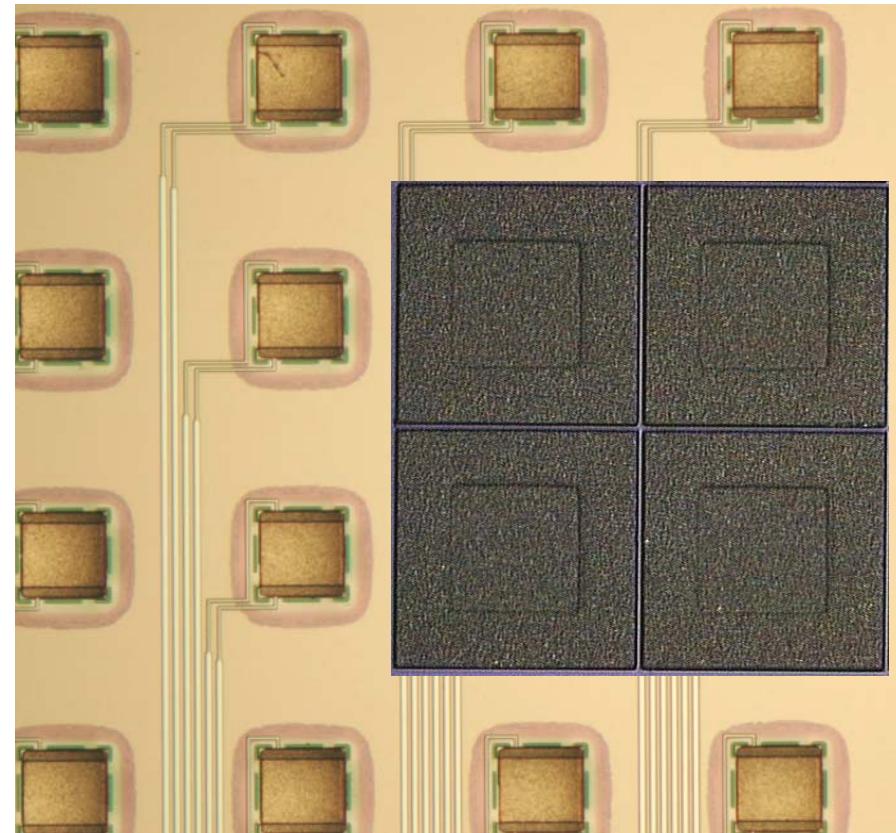


Constellation-X

Fabrication Examples



Array of identical devices

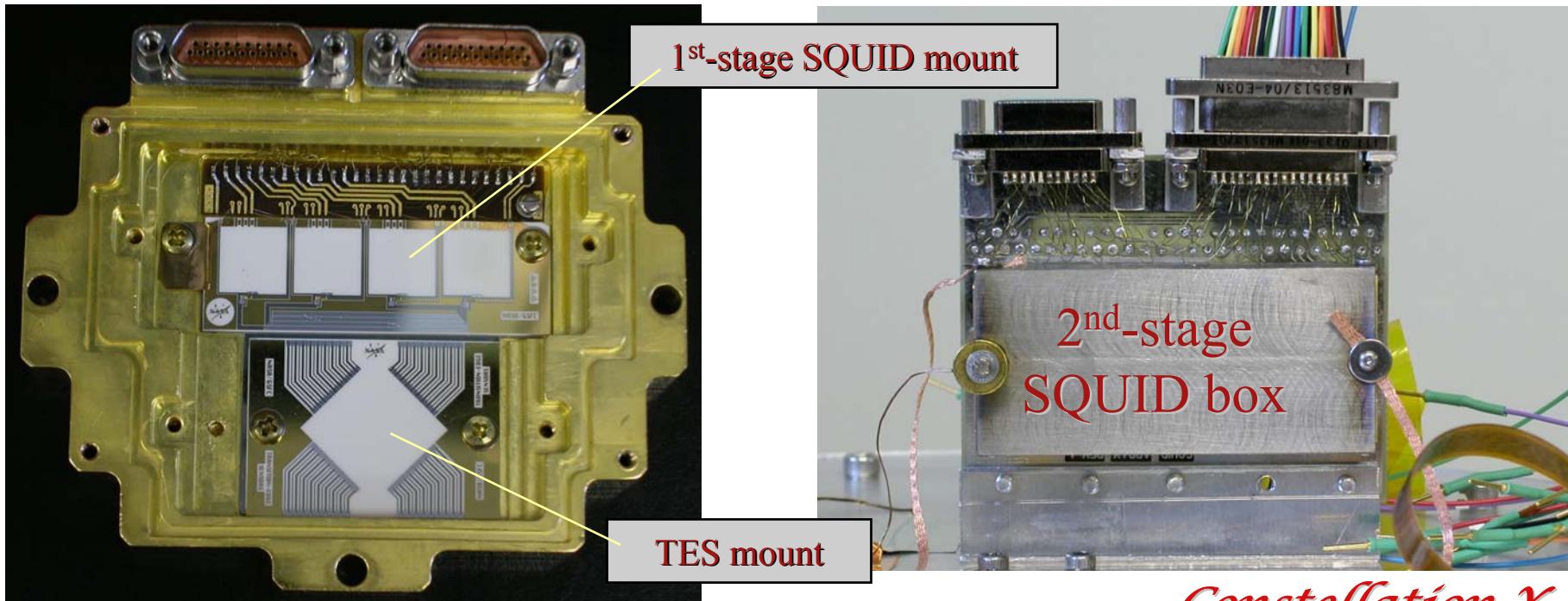


Sharp photolithography

Array of identical 150 micron devices. Soon will make these with 250 and 400 micron "mushroom" absorbers. The Bi absorbers shown are the size of the stem in the mushroom.

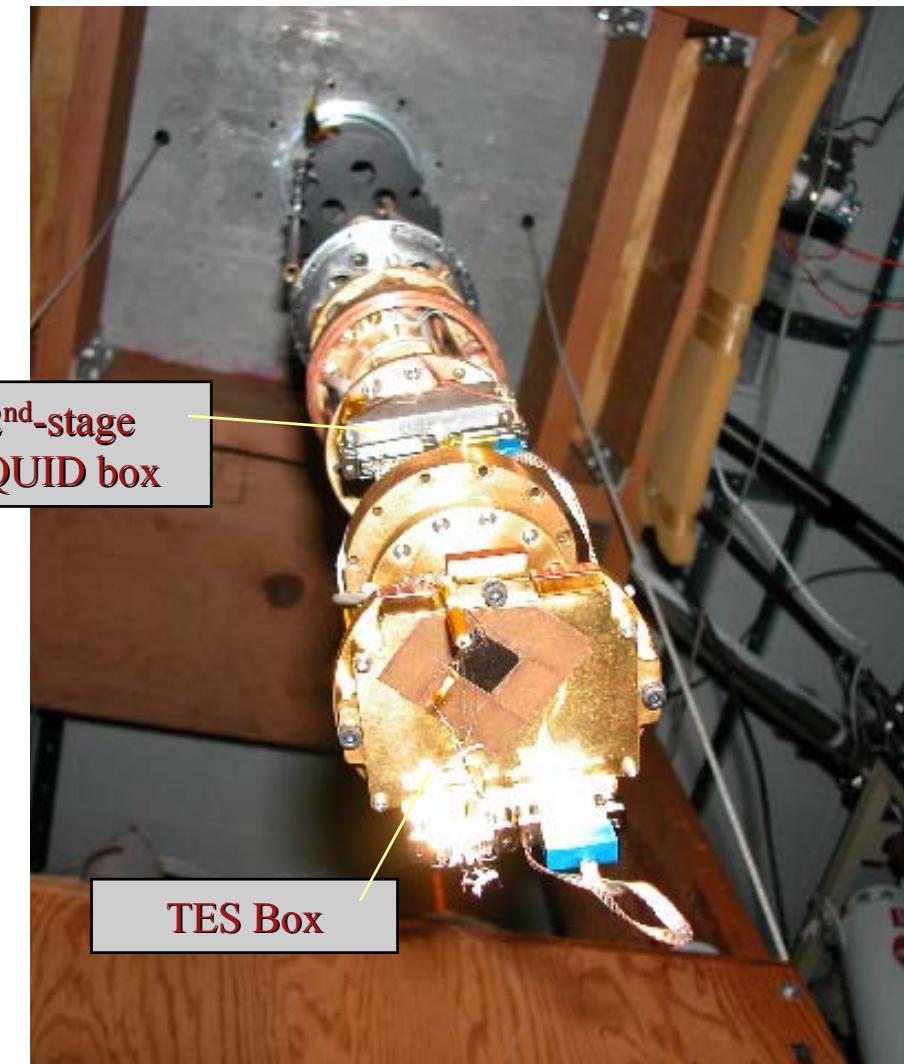
Infrastructure: Upgrading 4-channel Test Platform to 2-stage SQUID Readout

- Needed to keep solder joints out of the TES bias circuit
 - Superconducting wirebonds and film traces only
- Will provide robust, reliable test platform
- TES mounts and first-stage SQUID mounts made in-house
 - Alumina substrates with Au, Nb, and Al features



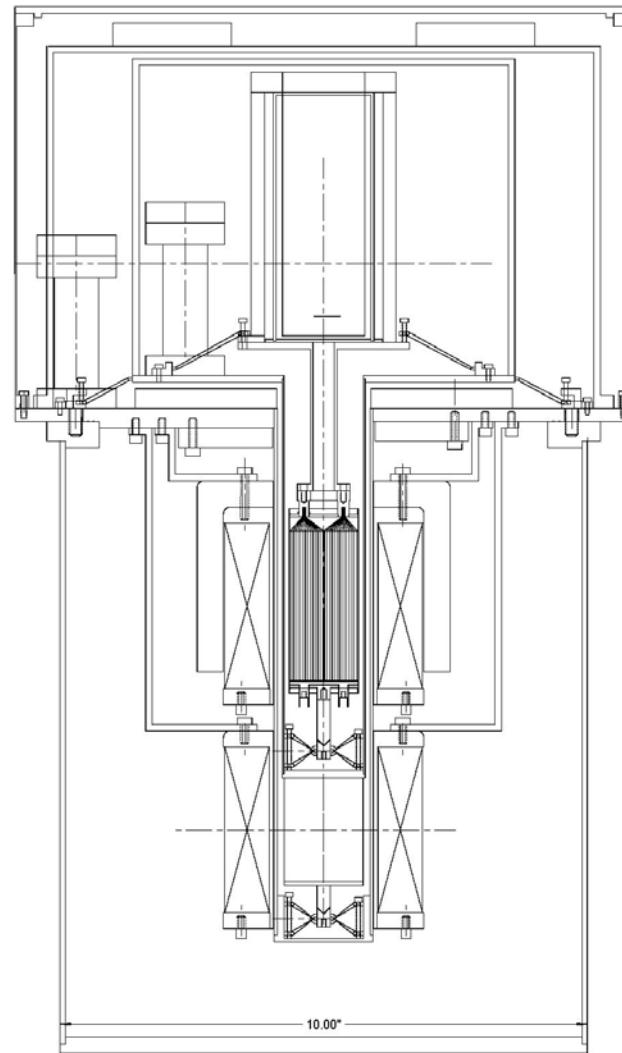
2-stage SQUID Readout now installed and operational

- Tested all 4 channels and confirmed all SQUIDs are operational.
- Demonstrated TES readout and obtained x-rays.



ADR Design and Construction

- Finished design of ADR
- Salt pill parts have been machined and are being assembled. First salt pill expected by end of Oct
- Suspension system is under testing
- On schedule for 2x8 demo

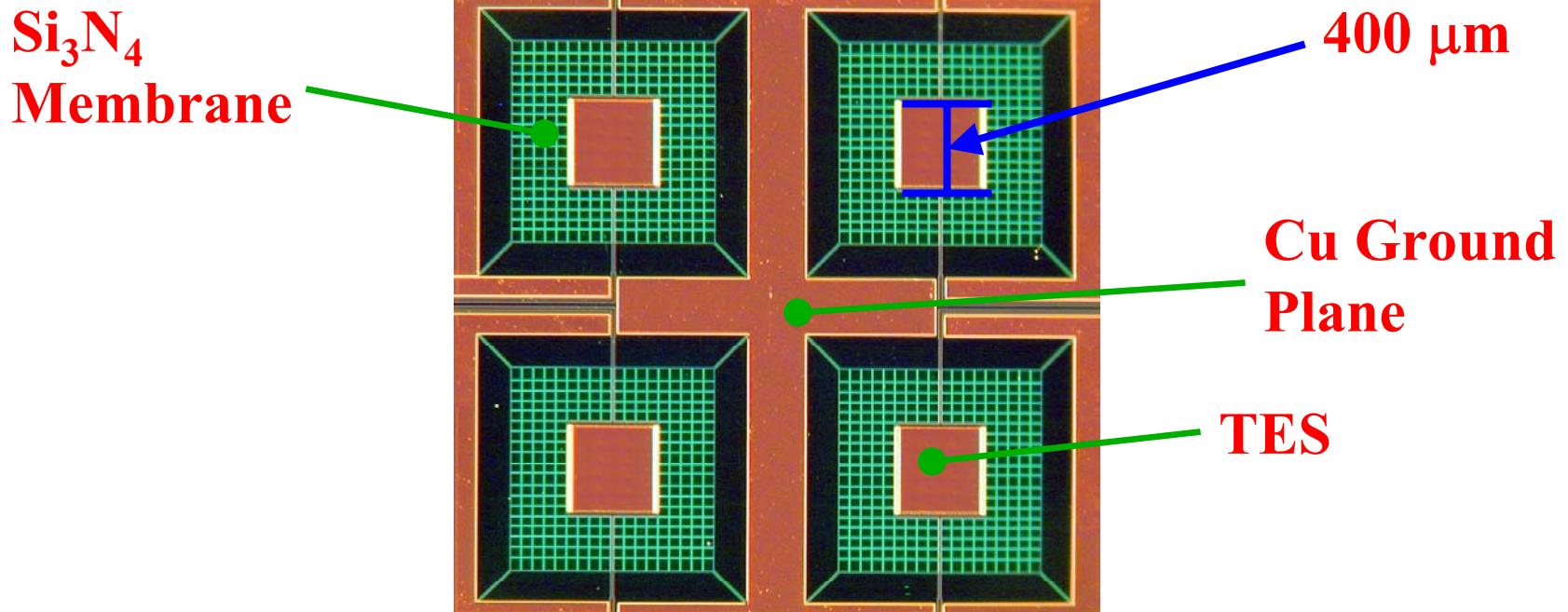




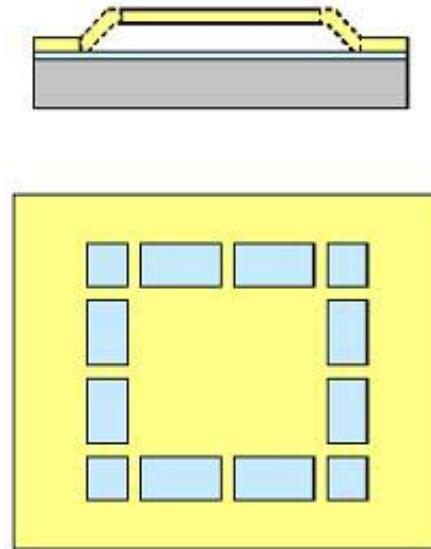
2 x 2 TES Array Demo

- **Array fabrication.**
- **Multiplexer integration.**
- **Testbed construction.**

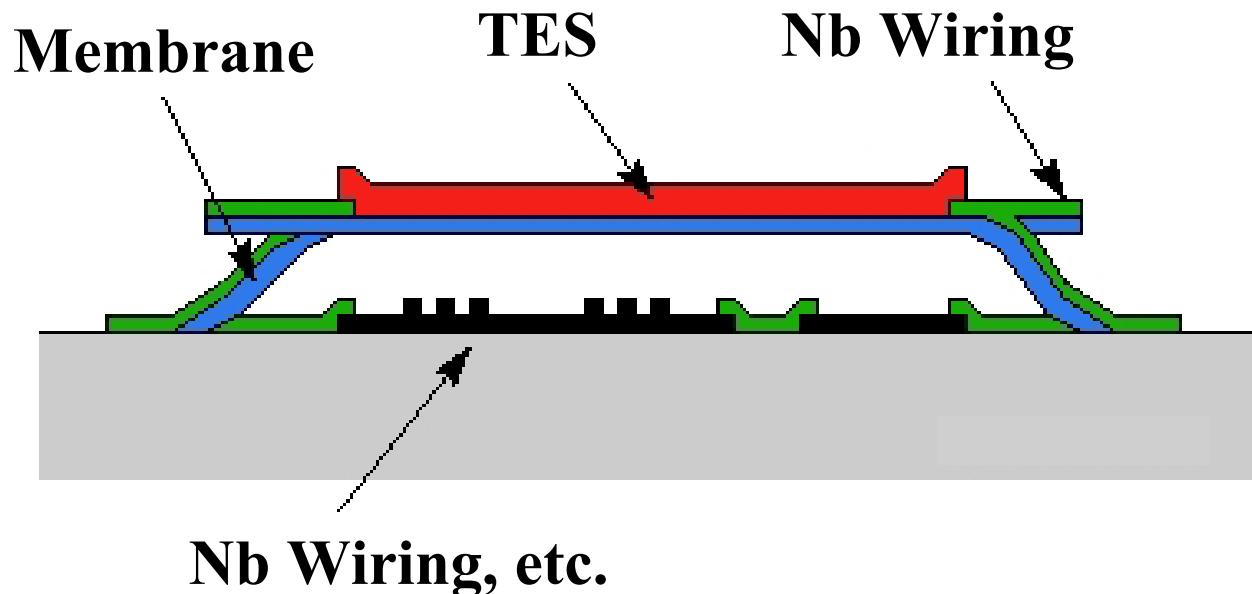
Old 2 x 2 Arrays



Membrane release



Surface Micromachined Array Wiring

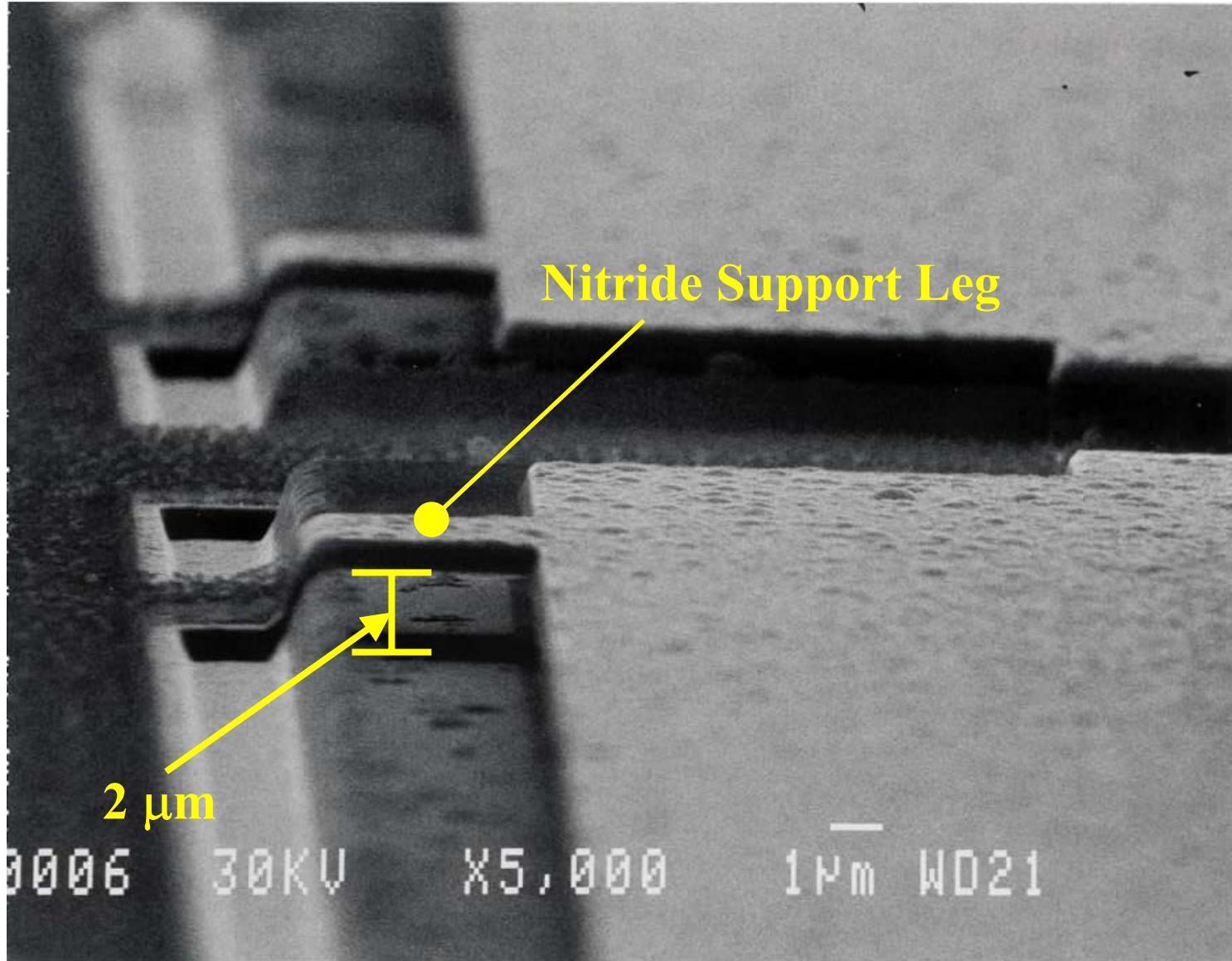


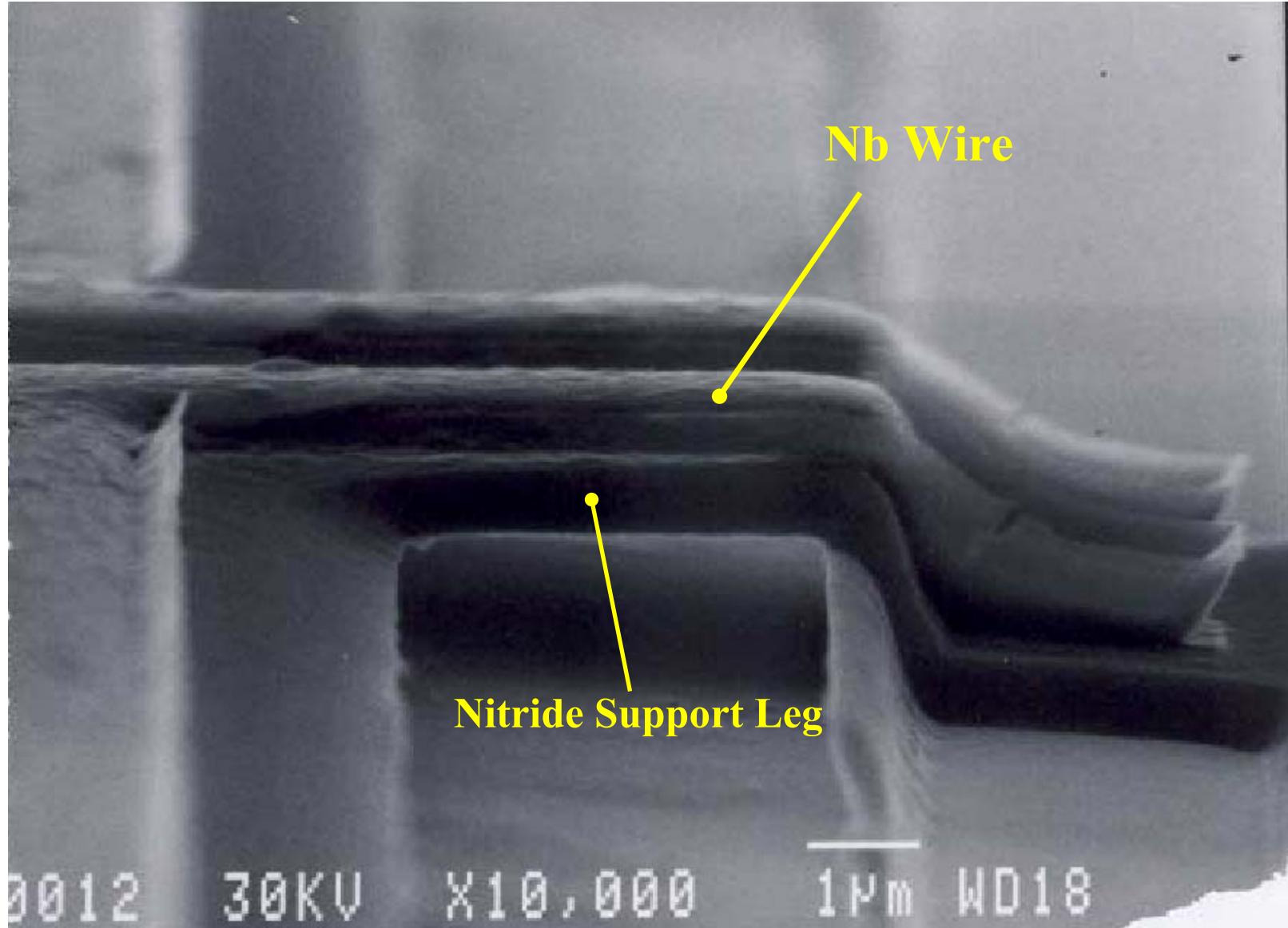
- Need pixels closer together.
- Use the area **under** the pixel for wiring.

Surface Micromachined Array Wiring

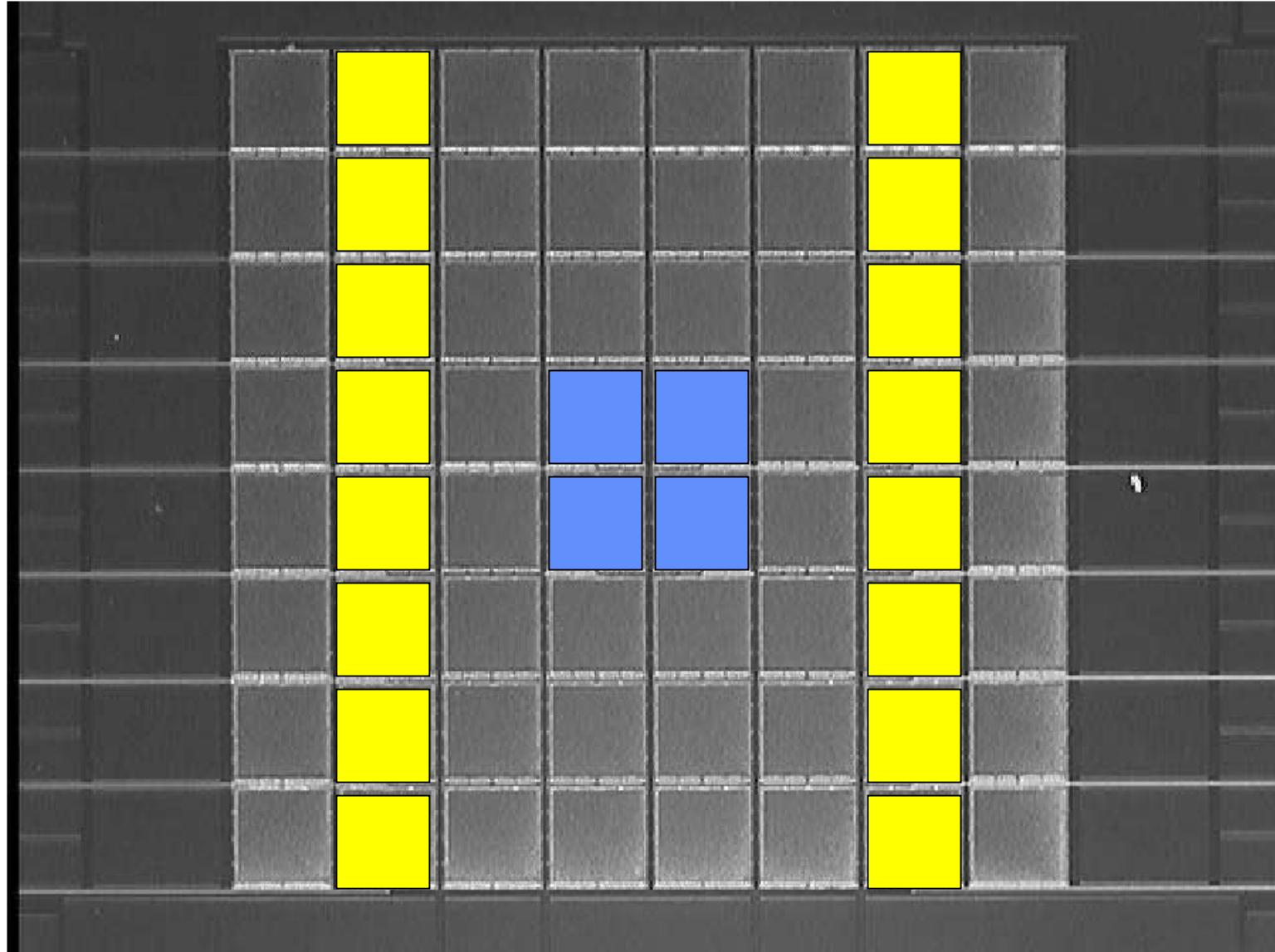
However...

- Polysilicon and nitride deposition processes are hot...~800 C !!
 - Will niobium wiring survive?
-
- Short answer: YES
 - Deposited polysilicon and nitride over niobium, then tested Nb T_C.
 - T_C changed from ~9K to ~7K
 - **Sufficient to wire a 32 x 32 array.**





Surface Micromachined 8x8 Array





Initial Results

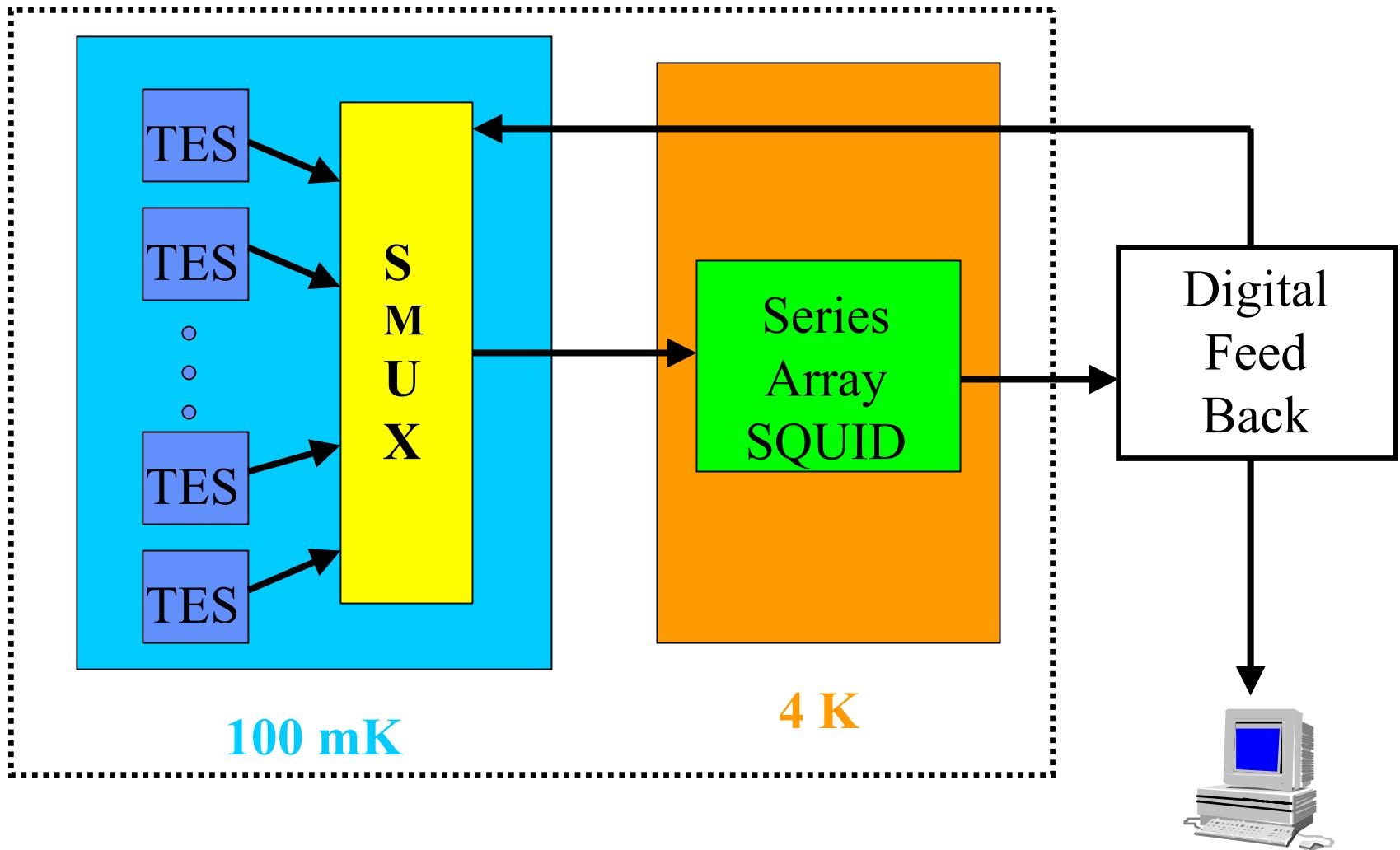
- Arrays fabricated and thermally cycled.
- Connectivity to the devices is good.
- Devices show good T_C .
- Further testing scheduled...next week!

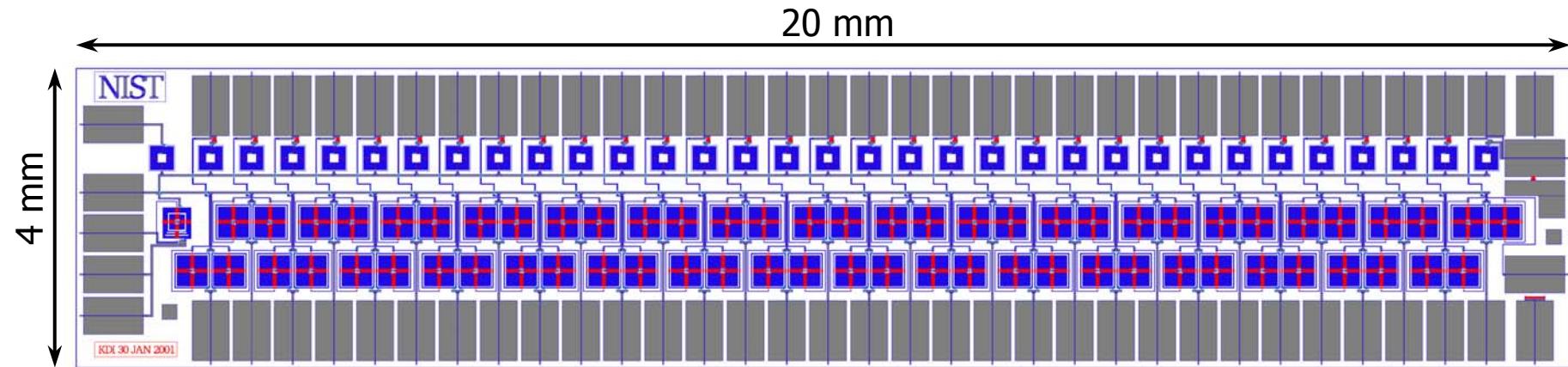


SQUID Multiplexing

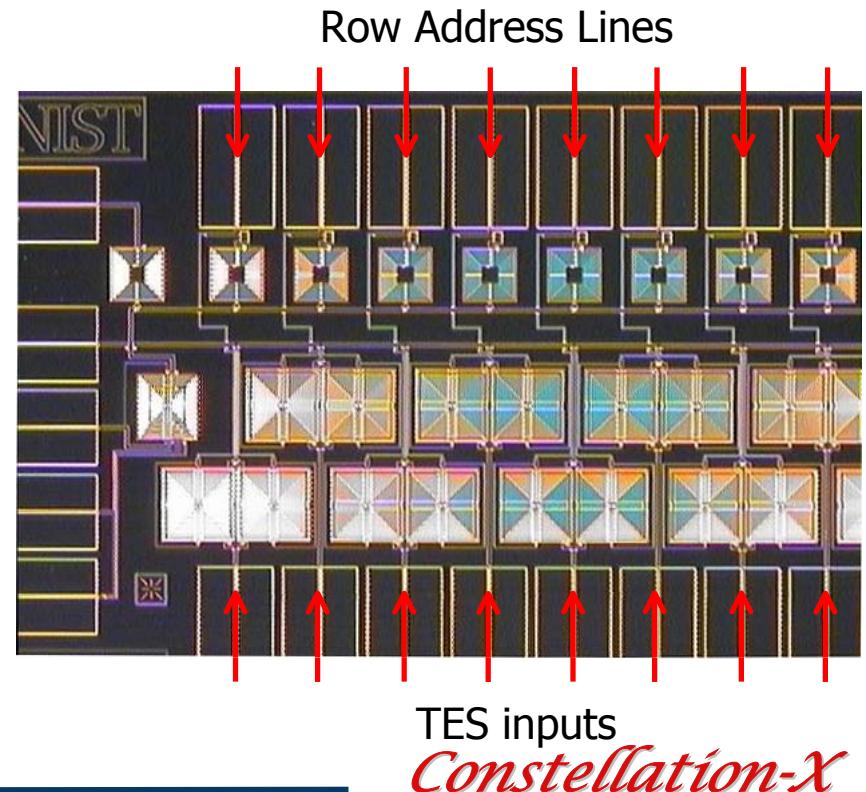


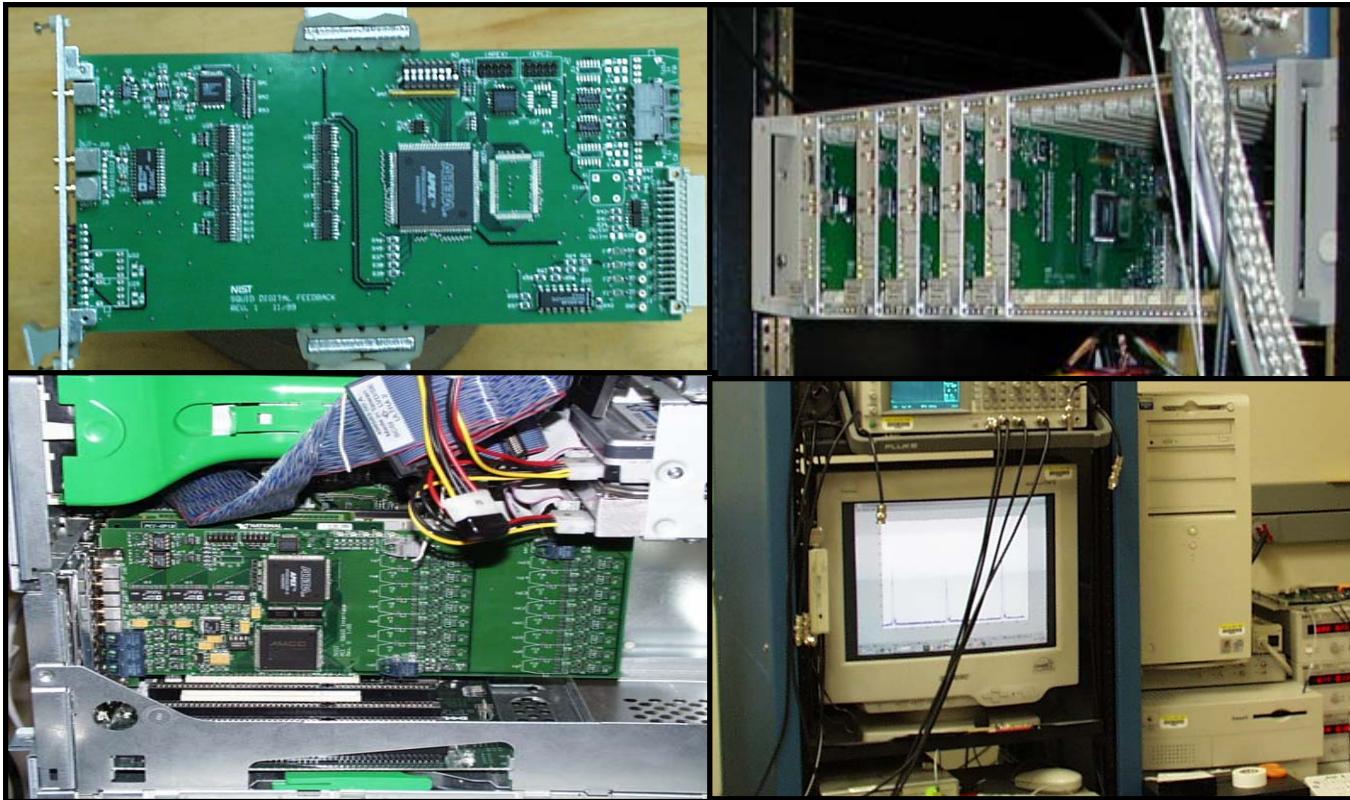
- There is a critical need to reduce the number of wires, and thus the heat load, from 0.1 K stage to 4 K stage.
- SQUIDs' superconducting nature allows for multiplexing.
- 1st generation SQUID MUX already deployed on a telescope.
- 2nd generation SQUID MUX now thoroughly tested and characterized.

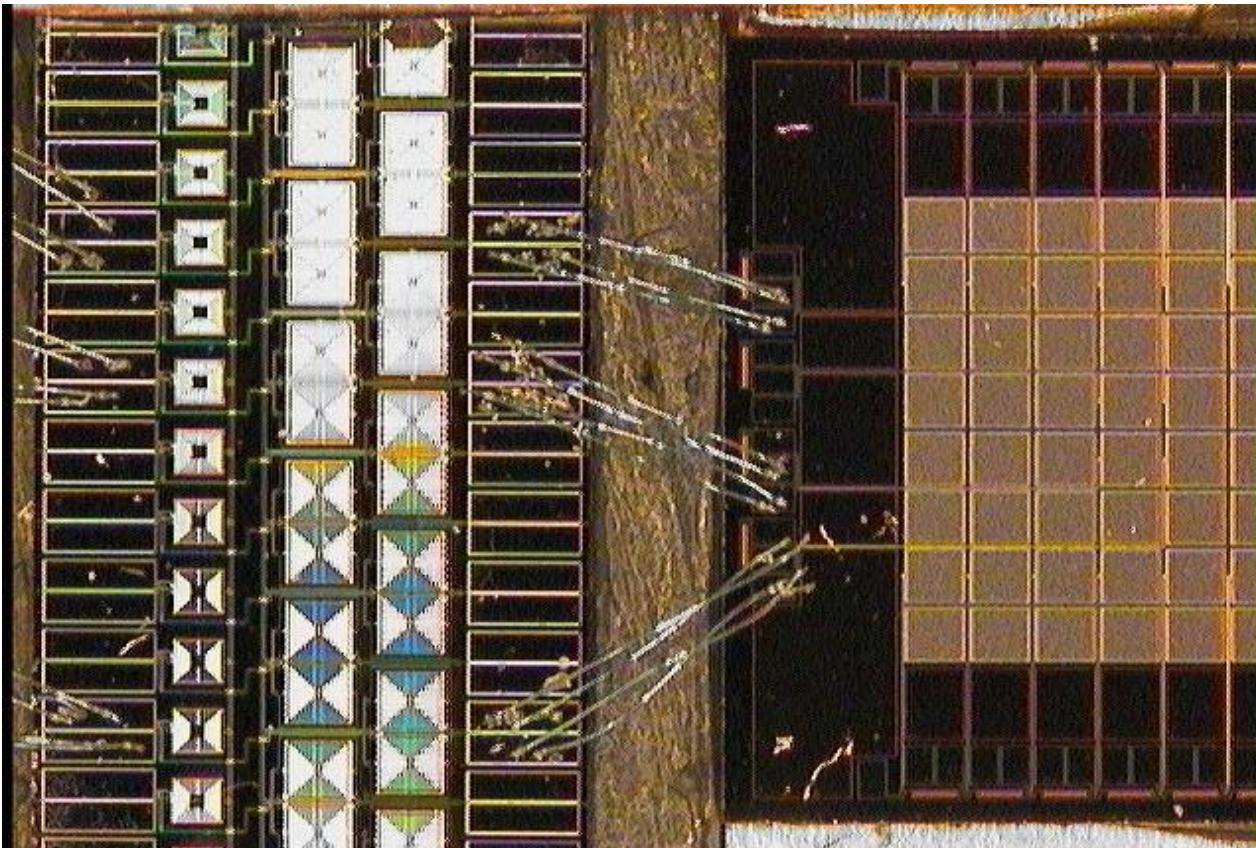




- 1 x 32 input SQUIDs per chip
- one column of 32 x 32 array
- Dissipated Power ≈ 4 nW
- Less than **1 μ W** for 32x32 array.







SQUID MUX chip

8x8 x-ray TES chip



Two limiting factors to multiplexing: noise and bandwidth.

NOISE LIMIT

$$N_{MAX} = 8 k_B T / 3 R_{TES} S_I^{SQ1}$$

$$T = 0.1 \text{ K} \quad R_{TES} \approx 5 \text{ m}\Omega$$

$$\sqrt{S_I^{SQ1}} = 3.2 \text{ pA} / \sqrt{\text{Hz}}$$

$$N_{MAX} \leq 70$$

BANDWIDTH LIMIT

Assuming a **100 μs** pulse:

SQUID MUX chip and 100mK
wiring:

$$N_{MAX} \leq 22$$

Room temp electronics:

$$N_{MAX} \leq 13$$

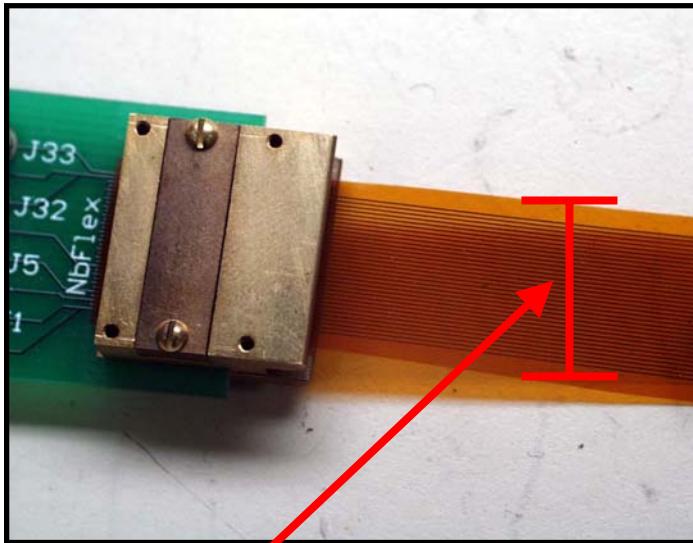


Room Temperature electronics:

- Increase clock speed on FPGA by factor of 2 to 3 easily.
- Use better electronic components on cards.
- Up to factor of 3 to 4 in N_{MAX}
- $N_{MAX} \leq 39\text{-}52$ for 100 μs pulses.

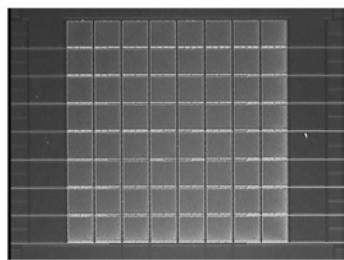
SQUID MUX and 100 mK wiring:

- 3rd generation SQUID MUX under development, higher bandwidth design.
- Lower inductance wiring at 100 mK.
- Up to factor of 2 to 3 in N_{MAX}
- $N_{MAX} \leq 44\text{-}66$ for 100 μs pulses.

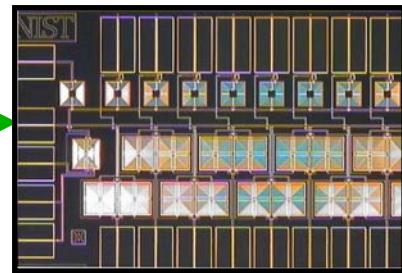
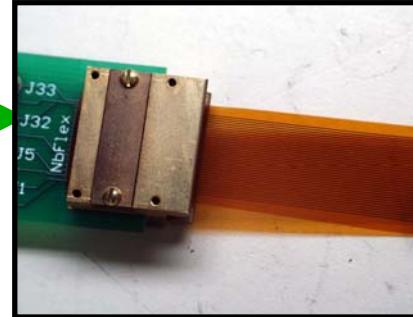


1/2 inch

- 32 channel superconducting flex.
- **Low inductance**
- Low thermal conductance
- Controlled impedance
- High density



8x8 Array

32 channel
SQUID
MUX

Nb Flex

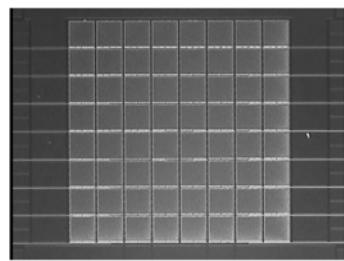


DFB cards

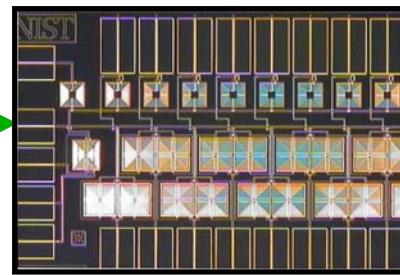
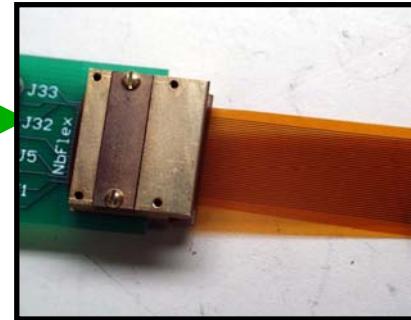


The components of a multiplexed array of TES x-ray detectors are in existence and ready to be integrated.





8x8 Array

32 channel
SQUID
MUX

Nb Flex

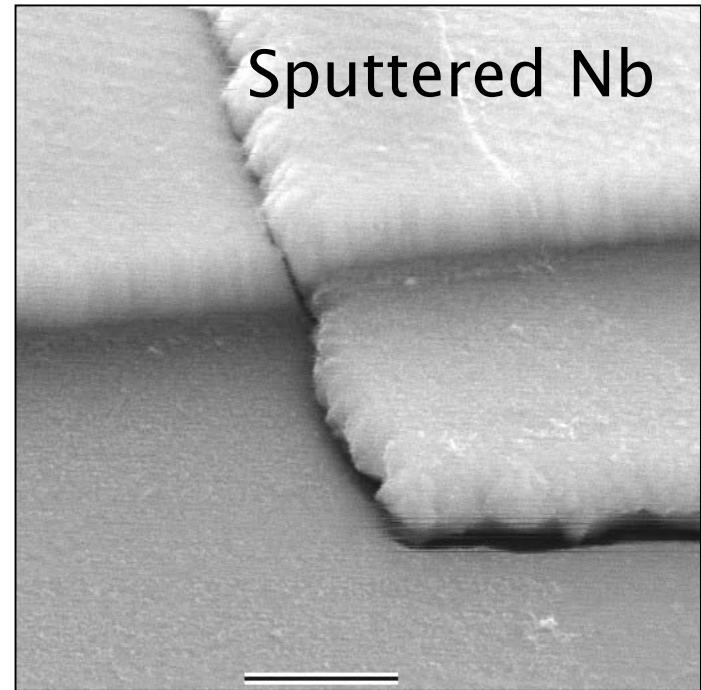


DFB cards

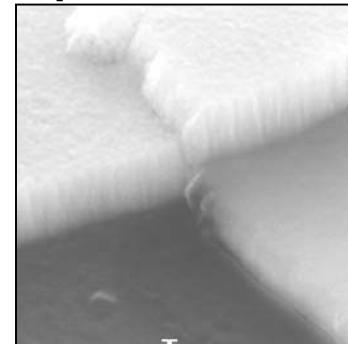
The components of a multiplexed array of TES x-ray detectors are in existence and ready to be integrated.

Leads and Step Coverage

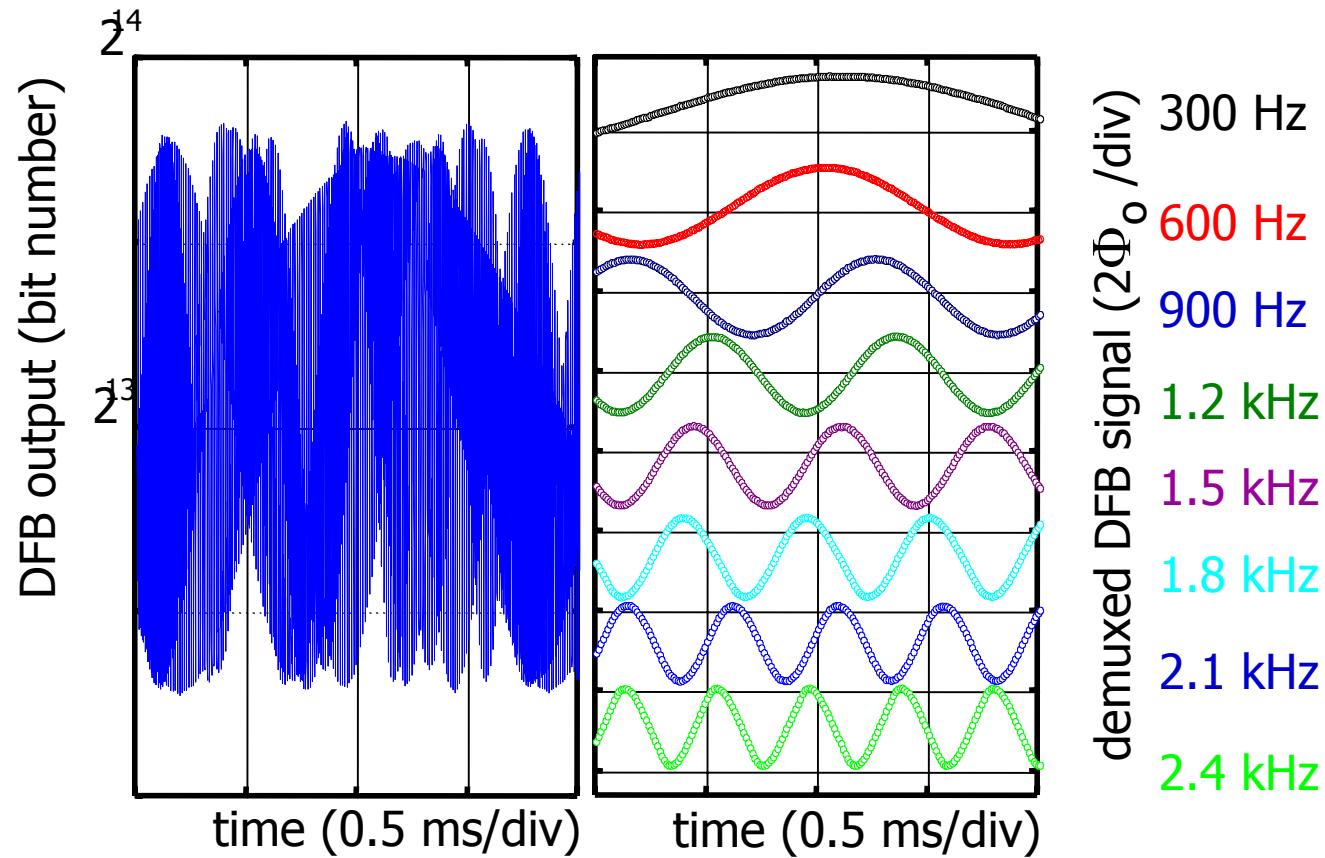
- We had problems with leads which we attributed to thicker films we were using
- The problem turned out to be due to inadequate step coverage of the Nb leads, which lead to the creation of a fissure at the step onto the TES
- This problem had existed all along, but was more noticeable on the thicker bilayers
- We have three solutions to this problem:
 - Al leads
 - Integrated Mo leads
 - Integrated Mo/Au/Mo leads

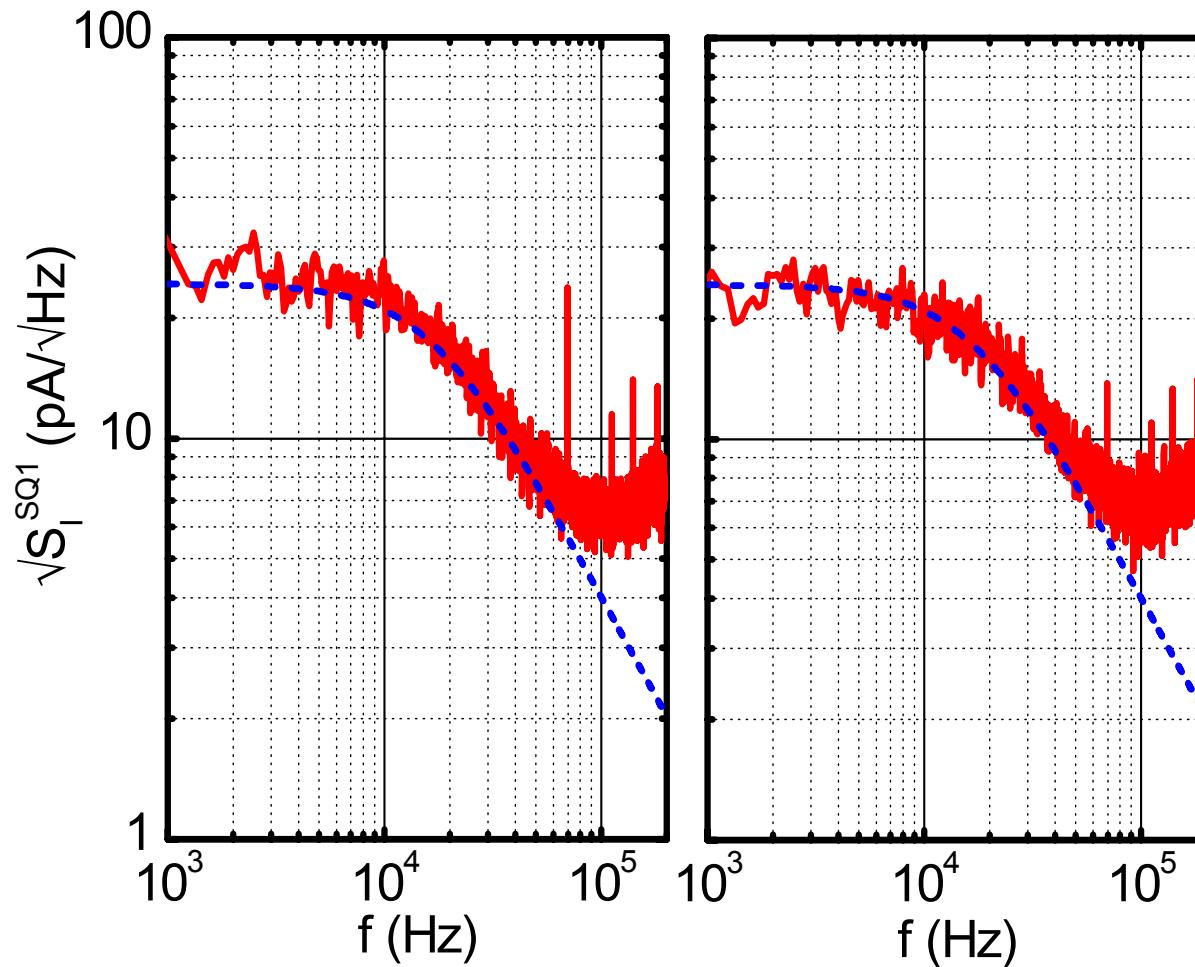


Evaporated Al



Constellation-X







Schedule (2 x 2)



2002

May	June	July	August	September	October	November	December
2-stage component testing	rewiring SHE DR for 2-stage	2-stage testing/troubleshooting one channel at a time					
					testing 4-channel electronics with and available TES arrays	official 4-channel demo	
		layout of 4-channel electronics		assembly of 4-channel electronics and data acquisition software modification			
continued production and development of TES arrays							